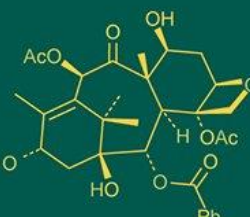
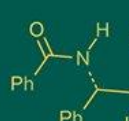
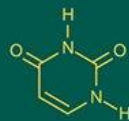


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Refrigerated shelf-life and quality stability of *O. Ficus-indica* fruit juice incorporated functional goat milk yoghurt spread

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Abstract

The present study investigated the refrigerated storage stability of a functional goat milk yoghurt spread enriched with *Opuntia ficus-indica* fruit juice. An optimized formulation containing goat milk standardized to 2.9% fat, concentrated yoghurt with 26% total solids and 20% *O. ficus-indica* fruit juice was evaluated during storage at $4 \pm 1^\circ\text{C}$ for 28 days and compared with a control. Changes in physicochemical, microbiological, antioxidant and sensory characteristics were monitored throughout storage. Both formulations exhibited relatively stable total solids and gradual post-acidification during storage. Water-holding capacity increased in developed goat milk yoghurt spread from 76.32% to 83.46%, indicating improved water retention and structural stabilization of the product matrix. Although viscosity increased during storage, goat milk yoghurt spread exhibited lower viscosity than the control, which was associated with improved spreadability. Viable populations of *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* remained above 10^6 CFU/g throughout the storage period, while yeasts, moulds, coliforms, *Escherichia coli* and coagulase-positive *Staphylococcus aureus* were not detected. The incorporation of *O. ficus-indica* fruit juice enhanced the functional properties of the product, as reflected by higher initial total phenolic content and substantial DPPH radical-scavenging activity. Sensory evaluation demonstrated superior retention of flavour, colour and appearance, body and texture, spreadability and overall acceptability in optimized product compared with the control. All sensory attributes of optimized product remained above the acceptable level after 28 days of refrigerated storage. The developed product was further observed up to 45 days, during which acceptable flavour and spreadability were retained despite slight surface whey separation. Based on the integrated physicochemical, microbiological and sensory evaluation, a confirmed refrigerated shelf-life of 28 days at $4 \pm 1^\circ\text{C}$ was established. The findings demonstrate the potential of *O. ficus-indica* fruit juice as a functional ingredient for developing a stable, value-added goat milk yoghurt spread.

Keywords: Goat milk, yoghurt spread, *Opuntia ficus-indica*, storage stability, antioxidant activity, water holding capacity

Introduction

The growing demand for foods that provide health benefits beyond basic nutrition has stimulated considerable interest in functional foods enriched with bioactive compounds. Fermented dairy products are particularly suitable for functional food development because of their high nutritional value, consumer acceptance and ability to act as carriers for plant-derived bioactive ingredients. However, the incorporation of such ingredients can significantly influence the physicochemical, biochemical, structural, microbiological and sensory properties of fermented dairy products, particularly during refrigerated storage (Arioui *et al.*, 2017) [7]. Goat milk is a valuable raw material for developing functional fermented dairy products owing to its distinctive nutritional composition, high digestibility and favourable technological properties. Compared with cow and buffalo milk, goat milk possesses differences in fatty acid and amino acid composition, which contribute to its characteristic flavour and aroma (Akshith *et al.*, 2024) [3]. Although these properties provide nutritional and functional advantages, the characteristic goaty flavour may influence consumer acceptance. Fermentation can improve the sensory characteristics and functional potential of goat milk products; however, continued biochemical and structural changes may occur during storage.

Recent studies have shown that goat milk yoghurt can retain desirable nutritional, sensory and biological properties during refrigerated storage, although changes in acidity, texture, antioxidant activity and microbial viability may occur depending on product formulation and starter culture (Yang *et al.*, 2023)^[24].

The incorporation of fruit-derived ingredients represents an effective strategy for enhancing the functional and sensory properties of fermented dairy products. *Opuntia ficus-indica* (OFI) is an underutilized fruit rich in phenolic compounds, flavonoids, betalains, carotenoids and other bioactive constituents associated with antioxidant and health-promoting properties (Alshaikhi *et al.*, 2023; Silva *et al.*, 2023; Ahmed *et al.*, 2024)^[2, 5]. Its incorporation into yoghurt products can influence their physicochemical and sensory characteristics (Arioui *et al.*, 2017)^[7], while the combination of OFI bioactives with the nutritional properties of goat milk may provide complementary functional benefits.

During fermentation and storage, phenolic compounds and other bioactive constituents may undergo release, transformation, oxidation or interactions with milk proteins, thereby affecting antioxidant activity and bioavailability. Concurrently, changes in acidity, protein-water interactions, moisture distribution, water-holding capacity, gel structure and rheological behaviour may influence the stability and acceptability of the product. In concentrated yoghurt systems, structural rearrangements during storage may further affect firmness, spreadability and whey separation. Therefore, assessment of storage stability requires an integrated evaluation of physicochemical, microbiological, functional, structural and sensory characteristics.

Although the functional potential of OFI has been investigated in various food systems, limited information is available regarding the storage stability of OFI fruit juice-enriched goat milk yoghurt spread. Therefore, the present study evaluated changes in the physicochemical, microbiological, antioxidant and sensory characteristics of an optimized OFI fruit juice-enriched goat milk yoghurt spread (OFI-GYS) during refrigerated storage, in comparison with a control concentrated yoghurt spread (OFI-CYS). The study further aimed to determine the storage stability and acceptable refrigerated shelf-life of the developed functional yoghurt spread under controlled storage conditions.

Materials and methods

Materials

Fresh goat milk obtained from Osmanabadi goats reared by local farmers in Mehsana district, Gujarat, India, was used for preparation of the yoghurt spread. Fresh, mature and undamaged OFI fruits were procured from the Rajkot region of Gujarat. Freeze-dried direct-vat-inoculation yoghurt culture POB-D (Dalton Biotecnologie, Italy) was used as the starter culture. Analytical-grade chemicals and microbiological media were procured from authorized suppliers.

Preparation of *Opuntia ficus-indica* fruit juice

Mature, ripe and undamaged *O. ficus-indica* fruits were selected, and visible thorns were removed. The fruits were washed with 100 ppm chlorine solution followed by potable water, peeled and cut into pieces. The pulp was strained through a wire mesh and muslin cloth to remove seeds and excess mucilage. The recovered juice was blanched at 90°C for 1-2 min, rapidly cooled and stored at -20°C until use.

Preparation of goat milk yoghurt spread

Goat milk was standardized to the desired fat content using the separated cream and skim milk and heat-treated at 90°C for 10 min. The milk was cooled to 42°C and inoculated with the freeze-dried yoghurt culture and incubated at 42°C until the titratable acidity reached 0.6% LA. The yoghurt was subsequently cooled to 4±1°C and concentrated by centrifugation to remove whey using basket centrifuge and standardized to 26% total solids content.

For preparation of the optimized fruit-enriched yoghurt spread, thawed *O. ficus-indica* juice was incorporated into the concentrated yoghurt at the optimized level, followed by the addition of sugar at 10% of the total product weight. The mixture was thermized at 65°C for 60s under aseptic conditions followed by subsequently cooling, then filled into sterilized PP cups, sealed and stored at 4±1°C. A control concentrated yoghurt spread prepared from mixed milk with same process. The optimized formulation consisted of goat milk standardized to 2.9% fat, concentrated yoghurt with 26% total solids and 20% *O. ficus-indica* juice addition.

Storage study

The optimized *O. ficus-indica* fruit juice-enriched goat milk yoghurt spread (OFI-GYS) and control concentrated yoghurt spread (OFI-CYS) were packed in 80g sealed polypropylene cups and stored at 4±1°C for 28 days. Samples were evaluated on Days 0, 7, 14, 21 and 28 to monitor changes during refrigerated storage. The storage study included physicochemical, microbiological, antioxidant and sensory analyses.

Physicochemical analysis

Total solid content was determined according to the FSSAI (2022) procedure. The pH of the samples was measured using a calibrated digital pH meter. Titratable acidity was determined by titration with standardized 0.1 N sodium hydroxide and expressed as percentage lactic acid. Viscosity was measured using a Brookfield DV3T viscometer equipped with spindle No. 63 at 60°C with a rotational speed of 0.3 rpm after 45 s of shearing.

Water-holding capacity

Water-holding capacity (WHC) was determined using method prescribed by Abdelmoneim *et al.* (2016)^[1]. Approximately 25g of yoghurt spread was centrifuged at 3500× g for 10 min at 4°C. The expelled whey was separated and weighed, and WHC was calculated based on the amount of water retained by the sample.

Microbiological analysis

Microbiological analyses were performed using standard serial dilution and plate-counting procedures. *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* were enumerated using M17 and acidified MRS agar, respectively. Coliforms, yeasts and moulds, *Escherichia coli* and coagulase-positive *Staphylococcus aureus* were evaluated using appropriate selective media and standard microbiological procedures. Results were expressed as log₁₀ CFU/g.

Antioxidant activity and total phenolic content

For extraction, yoghurt spread samples were centrifuged at 16,000 rpm for 30 min at 4°C. The supernatant was filtered and diluted with distilled water before analysis. Antioxidant

activity was determined using DPPH and ABTS radical-scavenging assays (El-Said *et al.*, 2014), and results were expressed as mM Trolox equivalents per 100 g of sample. Total phenolic content was determined using the Folin-Ciocalteu method (Lugo-Zarate *et al.*, 2021) and expressed as mg gallic acid equivalents per 100g. Total flavonoid content (Iftikhar *et al.*, 2023) ^[11, 16, 20] was determined using the aluminium chloride colorimetric method and expressed as mg rutin equivalents per 100 g.

Sensory evaluation

Sensory evaluation was conducted by a panel of 10 trained judges comprising faculty members, technical personnel and dairy professionals. Samples were evaluated using a nine-point hedonic scale for flavour, body and texture, colour and appearance, spreadability and overall acceptability. Sensory evaluation was conducted at the selected storage intervals to monitor changes in consumer acceptability during refrigerated storage. The sensory data were interpreted using the method Molina *et al.* (2019) ^[21] and average scores were calculated for each group of samples.

Statistical analysis

All analyses were performed using three experimental replicates, and results were expressed as mean $\pm$ standard deviation. Differences between treatments and storage periods were evaluated using analysis of variance (ANOVA), followed by Tukey's multiple-comparison test. Student's *t*-test was used where appropriate for comparison between two groups. Statistical significance was considered at $p < 0.05$. Statistical analyses were performed using GraphPad Prism version 8.4.2.

Results and Discussion

Changes in physicochemical properties during refrigerated storage

The changes in pH, titratable acidity (TA), total solids (TS), viscosity and water-holding capacity (WHC) of OFI-CYS and OFI-GYS during 28 days of refrigerated storage are presented in Table 1.

The initial pH values of OFI-CYS and OFI-GYS were 4.46 ± 0.04 and 4.49 ± 0.02 , respectively, with no significant difference ($p > 0.05$). A gradual decrease in pH was observed during storage, reaching 4.33 ± 0.03 and 4.37 ± 0.06 , respectively, on day 28. This progressive acidification may be attributed to the continued metabolic activity of starter cultures and organic acid production during refrigerated storage, as reported in yoghurt and fermented goat milk products (Aluko, 2025; de Oliveira *et al.*, 2025) ^[6, 8].

Consistent with the decrease in pH, TA increased progressively in both formulations. The acidity increased from 1.00 ± 0.01 to $1.10 \pm 0.02\%$ lactic acid in OFI-CYS and from 1.01 ± 0.01 to $1.11 \pm 0.01\%$ in OFI-GYS. OFI-CYS showed significantly higher acidity on days 7 and 14 ($p < 0.05$), although the difference disappeared by days 21 and 28. This temporary difference may reflect variations in buffering capacity and the influence of fruit juice constituents on post-acidification (Pinto *et al.*, 2017) ^[23]. Overall, the limited changes in pH and TA indicate that OFI incorporation did not adversely affect the acid balance of the yoghurt spread.

TS remained statistically unchanged during storage, ranging from 30.2-31.3% in OFI-CYS and 31.2-32.3% in OFI-GYS, indicating good compositional stability and limited moisture

migration. Viscosity increased significantly in both formulations, from $124,233 \pm 17,868$ to $186,000 \pm 8,190$ cP in OFI-CYS and from $47,400 \pm 6,239$ to $72,800 \pm 1,311$ cP in OFI-GYS. Nevertheless, OFI-CYS exhibited significantly higher viscosity throughout storage. The lower viscosity of OFI-GYS may be associated with the distinctive protein and fat characteristics of goat milk and the incorporation of fruit juice. Similar storage-related changes in viscosity have been reported in plant-fortified yoghurt systems (Elwahsh *et al.*, 2025) ^[13].

WHC increased in both products, from 81.94 ± 3.09 to $84.32 \pm 1.97\%$ in OFI-CYS and from 76.32 ± 2.22 to $83.46 \pm 2.44\%$ in OFI-GYS. Although OFI-GYS initially exhibited lower WHC, its marked improvement during storage indicates progressive structural rearrangement and stabilization of the yoghurt matrix. By day 28, its WHC was comparable to that of OFI-CYS.

Changes in sensory characteristics and determination of storage stability

Sensory acceptability is a critical determinant of the practical shelf-life of fermented dairy products. The changes in flavour, colour and appearance, body and texture, spreadability and overall acceptability of OFI-CYS and OFI-GYS during refrigerated storage are presented in Table 2.

The flavour score of OFI-GYS remained relatively stable throughout 28 days, decreasing non-significantly ($p > 0.05$) from 8.4 ± 0.69 to 7.9 ± 0.34 . In contrast, OFI-CYS showed a more pronounced decline from 8.5 ± 0.44 to 7.4 ± 0.41 , particularly during the later storage period. The better flavour retention of OFI-GYS may be associated with the composition of goat milk and the contribution of OFI fruit bioactive compounds, which may help moderate undesirable flavour development. Similar masking of goaty flavour in goat milk yoghurt following incorporation of oat flour has been reported by Alqahtani *et al.* (2021) ^[4].

Colour and appearance scores also remained significantly higher for OFI-GYS throughout storage. Although the score decreased from 8.4 ± 0.39 to 7.5 ± 0.47 , OFI-GYS showed better visual stability than OFI-CYS, which declined from 7.7 ± 0.47 to 6.4 ± 0.37 . This may be attributed to better retention of pigments and interactions between goat milk components and bioactive constituents of fruit. Similar colour changes have been reported in sheep yoghurt supplemented with prickly pear-derived ingredients (Muñoz-Tebar *et al.*, 2025) ^[22].

The greatest difference between the formulations was observed in body and texture. OFI-GYS retained higher scores throughout storage, declining from 8.4 ± 0.41 to 7.2 ± 0.24 , whereas OFI-CYS decreased from 7.1 ± 0.39 to 5.8 ± 0.54 . Likewise, spreadability declined in both samples but remained higher in OFI-GYS ($8.3-7.5$) than in OFI-CYS ($7.6-6.5$). The superior structural stability of OFI-GYS may be related to the distinctive protein and fat characteristics of goat milk, which contribute to improved gel integrity and spreadability.

Overall acceptability of OFI-GYS remained high, decreasing from 8.4 ± 0.31 to 7.5 ± 0.18 , while OFI-CYS declined from 7.7 ± 0.16 to 6.5 ± 0.20 . OFI-GYS retained scores above 7 for all sensory attributes at day 28, confirming acceptable sensory quality. OFI-CYS was not monitored beyond 28 days due to visible whey separation, colour fading and reduced sensory scores. In contrast, OFI-GYS remained sensorially acceptable during extended observation up to 45 days, despite

slight surface whey separation. Thus, the developed OFI-GYS demonstrated a confirmed sensory shelf-life of at least 28 days under refrigeration, with acceptable characteristics observed up to 45 days. Overall, OFI juice incorporation improved the sensory stability and storage performance of the goat milk yoghurt spread.

Changes in microbiological quality and starter culture viability during refrigerated storage

The changes in the viable counts of *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* in OFI-CYS and OFI-GYS during refrigerated storage are presented in Figure 1. Both formulations maintained viable lactic acid bacteria (LAB) counts above 10^6 CFU/g throughout the 28-day storage period, indicating the satisfactory survival of the yoghurt starter cultures under refrigerated conditions.

In OFI-CYS, the count of *L. bulgaricus* increased from $9.21 \pm 0.20 \log_{10}$ CFU/g on day 0 to $11.97 \pm 0.00 \log_{10}$ CFU/g on day 28. Similarly, OFI-GYS showed an increase from 8.46 ± 0.15 to $10.47 \pm 0.06 \log_{10}$ CFU/g during the same period. Although the counts increased progressively in both samples, OFI-CYS consistently exhibited significantly higher *L. bulgaricus* counts than OFI-GYS at each storage interval ($p < 0.05$). The substantial increase observed in OFI-GYS demonstrates that the incorporation of OFI fruit juice did not inhibit the survival of *L. bulgaricus* during refrigerated storage.

The population of *S. thermophilus* showed a comparatively moderate change during storage. In OFI-CYS, the count increased from $6.71 \log_{10}$ CFU/g on day 0 to $7.35 \log_{10}$ CFU/g on day 28. OFI-GYS initially showed a slight decline from 6.14 to $5.85 \log_{10}$ CFU/g by day 7, followed by a gradual increase to $7.28 \log_{10}$ CFU/g at the end of storage. This initial reduction may represent a short adaptation phase to the storage environment and the specific physicochemical conditions of the goat milk yoghurt matrix. Subsequent recovery and increase in the *S. thermophilus* population may be related to continued metabolic activity and post-acidification during refrigerated storage. Similar fluctuations in starter culture populations during storage have been attributed to changes in nutrient availability, accumulation of metabolic products and adaptation of microorganisms to the changing yoghurt environment (Latifasari *et al.*, 2024; Lim *et al.*, 2024) [18, 19].

Both starter cultures remained viable at levels considerably higher than the commonly recognized threshold of 10^6 CFU/g throughout storage. Furthermore, the presence of *O. ficus-indica* fruit juice did not prevent the growth or persistence of either starter organism. Similar findings have been reported in fruit-enriched fermented dairy products, where the incorporation of prickly pear-derived ingredients did not adversely affect the survival of starter cultures (Muñoz-Tebar *et al.*, 2025) [22].

From a safety perspective, yeasts, moulds, coliforms, *Escherichia coli* and coagulase-positive *Staphylococcus aureus* were not detected in either formulation during the entire 28-day storage period.

Overall, the microbiological results demonstrate that the incorporation of OFI fruit juice was compatible with the yoghurt starter cultures and did not compromise the microbiological safety of the product.

Changes in antioxidant potential during refrigerated storage: The changes in antioxidant potential of optimized

product and control are depicted in Table 3. Refrigerated storage significantly influenced the antioxidant potential and bioactive composition of the yoghurt spreads, although the magnitude and pattern of changes varied between assays. The DPPH radical-scavenging activity of both OFI-CYS and OFI-GYS increased significantly up to day 7, reaching 391.1 ± 6.22 and 398.9 ± 7.31 mM TE/100 g, respectively. Thereafter, a marked decline was observed on day 14, followed by a slight recovery during the subsequent storage period. The highest DPPH activity was recorded in OFI-GYS on day 7 (438.6 ± 4.39 mM TE/100 g), although the value was statistically comparable with OFI-CYS (435.8 ± 6.22 mM TE/100 g). The initial increase may be associated with the release of antioxidant peptides and phenolic compounds through continued microbial activity and proteolysis during storage. Conversely, the subsequent reduction may be attributed to oxidation and degradation of phenolic compounds, as well as interactions between polyphenols and milk proteins or peptides (Jiménez-Redondo *et al.*, 2022; Durmus *et al.*, 2021; Zhao *et al.*, 2021). Similar storage-related changes in antioxidant activity have been reported in fortified yoghurt systems (El-Sayed *et al.*, 2019; Elwahsh *et al.*, 2025) [10, 12, 13, 17, 26].

In contrast, the ABTS assay clearly demonstrated the antioxidant advantage of OFI fortification. OFI-GYS exhibited significantly higher activity than OFI-CYS throughout storage, with values of 519.0 ± 2.93 and 316.4 ± 4.20 mM TE/100 g, respectively, on day 0. Although ABTS activity declined during storage, OFI-GYS retained higher activity on day 28, indicating better preservation of antioxidant potential. Differences between DPPH and ABTS responses may be related to the distinct reaction mechanisms and solvent-dependent extraction of antioxidant compounds. The superior antioxidant performance of OFI-GYS was further supported by its higher retention of phenolic compounds. Total phenolic content in OFI-GYS increased slightly from 21.9 to 22.5 mg GAE/100 g by day 7 and subsequently declined to 19.9 mg GAE/100 g on day 28. In comparison, OFI-CYS decreased from 20.3 to 18.9 mg GAE/100 g. The higher phenolic content of OFI-GYS may be attributed to the polyphenols and betalains naturally present in OFI fruit (Zenteno-Ramírez *et al.*, 2018; Duque-Buitrago *et al.*, 2024) [9, 25]. The relatively better retention of phenolics in OFI-GYS may also reflect interactions with goat milk proteins, which can protect bioactive compounds from degradation.

In case of Total flavonoid content, OFI-GYS maintained its flavonoid content during storage and reached 8.1 mg RE/100 g on day 28, whereas OFI-CYS declined significantly to 3.9 mg RE/100 g. This improvement may be related to the gradual release of bound flavonoids or microbial biotransformation of glycosylated compounds during storage. Overall, OFI juice incorporation enhanced the antioxidant and bioactive potential of goat milk yoghurt spread and contributed to improved retention of functional compounds during refrigerated storage.

Integrated assessment of storage stability

The overall storage stability of the optimized OFI fruit juice-enriched goat milk yoghurt spread (OFI-GYS) was assessed by integrating physicochemical, microbiological, antioxidant and sensory characteristics during refrigerated storage. OFI-GYS showed satisfactory stability over 28 days, with only gradual changes in pH and acidity and no significant

alteration in total solids. The increase in water-holding capacity from 76.32% to 83.46% indicated improved water retention and structural stability during storage.

Both *L. bulgaricus* and *S. thermophilus* remained viable above 10^6 CFU/g throughout storage, while yeasts, moulds, coliforms, *E. coli* and coagulase-positive *S. aureus* were not detected. The product also retained measurable antioxidant activity and higher phenolic content than the control, confirming the persistence of functional bioactive compounds in the fermented matrix.

Sensory evaluation provided strong evidence of improved storage stability. OFI-GYS maintained significantly higher scores for body and texture, colour and appearance, spreadability and overall acceptability than OFI-CYS, retaining scores above 7 for all attributes on day 28. Although slight surface whey separation was observed during extended observation up to 45 days, acceptable flavour and spreadability were retained. Therefore, OFI-GYS demonstrated a validated refrigerated shelf-life of 28 days at $4 \pm 1^\circ\text{C}$, with potential for further extension following additional validation.

Table 1: Effect of refrigerated storage on pH, titratable acidity, TS, Viscosity, and WHC of OFI-GYS and OFI-CYS

Parameters	Samples	Storage days				
		0	7	14	21	28
pH	OFI-CYS	$4.46 \pm 0.04^{\text{aA}}$	$4.45 \pm 0.05^{\text{aA}}$	$4.40 \pm 0.03^{\text{aA}}$	$4.35 \pm 0.06^{\text{aA}}$	$4.33 \pm 0.03^{\text{aA}}$
	OFI-GYS	$4.49 \pm 0.02^{\text{aA}}$	$4.50 \pm 0.03^{\text{aA}}$	$4.47 \pm 0.06^{\text{aA}}$	$4.44 \pm 0.05^{\text{aA}}$	$4.37 \pm 0.06^{\text{aA}}$
TA (%LA)	OFI-CYS	$1.00 \pm 0.01^{\text{aB}}$	$1.08 \pm 0.02^{\text{aA}}$	$1.09 \pm 0.02^{\text{aA}}$	$1.10 \pm 0.01^{\text{aA}}$	$1.10 \pm 0.02^{\text{aA}}$
	OFI-GYS	$1.01 \pm 0.01^{\text{aB}}$	$1.02 \pm 0.02^{\text{bB}}$	$1.03 \pm 0.01^{\text{bB}}$	$1.08 \pm 0.02^{\text{aA}}$	$1.11 \pm 0.01^{\text{aA}}$
TS (%)	OFI-CYS	$31.0 \pm 0.93^{\text{aA}}$	$30.2 \pm 1.04^{\text{aA}}$	$30.2 \pm 0.66^{\text{aA}}$	$31.3 \pm 0.16^{\text{aA}}$	$30.5 \pm 0.32^{\text{aA}}$
	OFI-GYS	$32.3 \pm 0.61^{\text{aA}}$	$31.9 \pm 0.44^{\text{aA}}$	$31.4 \pm 0.87^{\text{aA}}$	$32.3 \pm 0.12^{\text{aA}}$	$31.2 \pm 0.67^{\text{aA}}$
Viscosity at 60°C (cP)	OFI-CYS	$124233 \pm 17868^{\text{aC}}$	$111933 \pm 4835^{\text{aC}}$	$128567 \pm 2797^{\text{aC}}$	$152767 \pm 5908^{\text{aB}}$	$186000 \pm 8190^{\text{aA}}$
	OFI-GYS	$47400 \pm 6239^{\text{bB}}$	$54200 \pm 1637^{\text{bAB}}$	$58067 \pm 1270^{\text{bAB}}$	$62600 \pm 1709^{\text{bAB}}$	$72800 \pm 1311^{\text{bA}}$
WHC (%)	OFI-CYS	$81.94 \pm 3.09^{\text{aA}}$	$82.61 \pm 1.51^{\text{aA}}$	$78.53 \pm 2.05^{\text{aA}}$	$83.28 \pm 0.63^{\text{aA}}$	$84.32 \pm 1.97^{\text{aA}}$
	OFI-GYS	$76.32 \pm 2.22^{\text{aB}}$	$77.08 \pm 3.61^{\text{aAB}}$	$77.39 \pm 3.74^{\text{aAB}}$	$80.94 \pm 1.03^{\text{aAB}}$	$83.46 \pm 2.44^{\text{aA}}$

Values are mean $\pm$ SD for $n=3$. Different lowercase letters indicate statistically significant differences ($p < 0.05$) between samples (OFI-CYS, OFI-GYS) according to Tukey's test.

Different uppercase letters indicate statistically significant differences ($p < 0.05$) between storage time according to Tukey's test

Table 2: Effect of refrigerated storage on sensory characteristics of OFI-GYS

Sensory attributes	Samples	Time in Days				
		0	7	14	21	28
Flavour	OFI-CYS	$8.5 \pm 0.44^{\text{aA}}$	$8.3 \pm 0.63^{\text{aAB}}$	$8.2 \pm 0.47^{\text{aAB}}$	$7.7 \pm 0.41^{\text{aBC}}$	$7.4 \pm 0.41^{\text{aC}}$
	OFI-GYS	$8.4 \pm 0.69^{\text{aA}}$	$8.4 \pm 0.66^{\text{aA}}$	$8.2 \pm 0.58^{\text{aA}}$	$8.1 \pm 0.37^{\text{aA}}$	$7.9 \pm 0.34^{\text{aA}}$
Colour & Appearance	OFI-CYS	$7.7 \pm 0.47^{\text{bA}}$	$7.4 \pm 0.52^{\text{bAB}}$	$7.1 \pm 0.57^{\text{bABC}}$	$6.8 \pm 0.54^{\text{bBC}}$	$6.4 \pm 0.37^{\text{bC}}$
	OFI-GYS	$8.4 \pm 0.39^{\text{aA}}$	$8.4 \pm 0.41^{\text{aA}}$	$8.3 \pm 0.42^{\text{aA}}$	$7.8 \pm 0.63^{\text{bAB}}$	$7.5 \pm 0.47^{\text{bB}}$
Body & Texture	OFI-CYS	$7.1 \pm 0.39^{\text{bA}}$	$6.7 \pm 0.58^{\text{bAB}}$	$6.4 \pm 0.47^{\text{bBC}}$	$6.2 \pm 0.57^{\text{bBC}}$	$5.8 \pm 0.54^{\text{bC}}$
	OFI-GYS	$8.4 \pm 0.41^{\text{aA}}$	$8.4 \pm 0.41^{\text{aA}}$	$8.2 \pm 0.24^{\text{aA}}$	$7.9 \pm 0.31^{\text{aA}}$	$7.2 \pm 0.24^{\text{aB}}$
Spreadability	OFI-CYS	$7.6 \pm 0.44^{\text{bA}}$	$7.3 \pm 0.35^{\text{bA}}$	$7.1 \pm 0.44^{\text{bAB}}$	$7.0 \pm 0.33^{\text{bAB}}$	$6.5 \pm 0.43^{\text{bB}}$
	OFI-GYS	$8.3 \pm 0.42^{\text{aA}}$	$8.3 \pm 0.48^{\text{aA}}$	$8.0 \pm 0.49^{\text{aAB}}$	$7.9 \pm 0.31^{\text{aAB}}$	$7.5 \pm 0.41^{\text{aB}}$
Overall Acceptability	OFI-CYS	$7.7 \pm 0.16^{\text{bA}}$	$7.4 \pm 0.37^{\text{bA}}$	$7.1 \pm 0.23^{\text{bA}}$	$6.9 \pm 0.29^{\text{bB}}$	$6.5 \pm 0.20^{\text{bC}}$
	OFI-GYS	$8.4 \pm 0.31^{\text{aA}}$	$8.4 \pm 0.33^{\text{aB}}$	$8.2 \pm 0.21^{\text{aBC}}$	$7.9 \pm 0.23^{\text{aC}}$	$7.5 \pm 0.18^{\text{aD}}$

Values are mean $\pm$ SD for $n=10$. Different lowercase letters indicate statistically significant differences ($p < 0.05$) between samples (OFI-CYS, OFI-GYS) according to Tukey's test.

Different uppercase letters indicate statistically significant differences ($p < 0.05$) between storage time according to Tukey's test.

Table 3: Effect of refrigerated storage on antioxidant potential of OFI-GYS

Sensory attributes	Samples	Time in Days				
		0	7	14	21	28
DPPH Radical Scavenging Activity (mM TE/100g)	OFI-CYS	$322.4 \pm 9.19^{\text{aB}}$	$391.1 \pm 6.22^{\text{aA}}$	$208.1 \pm 7.58^{\text{aE}}$	$246.5 \pm 2.05^{\text{aD}}$	$282.1 \pm 4.80^{\text{aC}}$
	OFI-GYS	$319.4 \pm 3.93^{\text{aB}}$	$398.9 \pm 7.31^{\text{aA}}$	$207.8 \pm 6.11^{\text{aE}}$	$251.8 \pm 1.93^{\text{aD}}$	$278.1 \pm 4.07^{\text{aC}}$
ABTS Radical Scavenging Activity (mM TE/100g)	OFI-CYS	$316.4 \pm 4.20^{\text{bA}}$	$243.4 \pm 6.87^{\text{bC}}$	$264.7 \pm 7.35^{\text{bB}}$	$231.9 \pm 6.38^{\text{bC}}$	$232.5 \pm 2.35^{\text{bC}}$
	OFI-GYS	$519.0 \pm 2.93^{\text{aA}}$	$265.3 \pm 3.11^{\text{aC}}$	$295.0 \pm 4.63^{\text{aB}}$	$269.0 \pm 1.92^{\text{aC}}$	$264.7 \pm 6.20^{\text{aC}}$
Total phenolics (mg GAE/100g)	OFI-CYS	$20.3 \pm 0.86^{\text{bA}}$	$19.6 \pm 0.22^{\text{bAB}}$	$18.2 \pm 0.31^{\text{bC}}$	$18.7 \pm 0.29^{\text{bBC}}$	$18.9 \pm 0.43^{\text{aBC}}$
	OFI-GYS	$21.9 \pm 0.17^{\text{aA}}$	$22.5 \pm 0.60^{\text{aA}}$	$20.5 \pm 0.28^{\text{aBC}}$	$21.3 \pm 0.30^{\text{aAB}}$	$19.9 \pm 0.26^{\text{aC}}$
Total flavonoids (mg RE/100g)	OFI-CYS	$5.8 \pm 0.39^{\text{aA}}$	$5.9 \pm 0.30^{\text{aA}}$	$5.1 \pm 0.07^{\text{aAB}}$	$6.4 \pm 0.34^{\text{aA}}$	$3.9 \pm 0.19^{\text{bB}}$
	OFI-GYS	$7.0 \pm 0.64^{\text{aAC}}$	$6.6 \pm 0.10^{\text{aC}}$	$5.6 \pm 0.52^{\text{aB}}$	$7.1 \pm 0.99^{\text{aAC}}$	$8.1 \pm 0.20^{\text{aA}}$

Values are mean $\pm$ SD for $n=3$. Different lowercase letters indicate statistically significant differences ($p < 0.05$) between samples (OFI-CYS, OFI-GYS) according to Tukey's test.

Different uppercase letters indicate statistically significant differences ($p < 0.05$) between storage time according to Tukey's test.

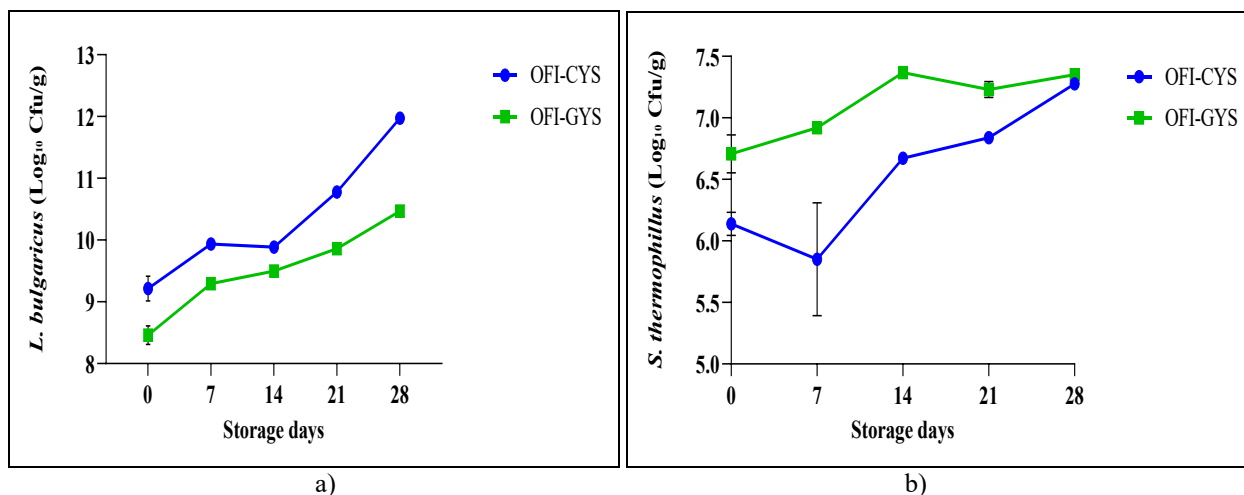


Fig 1: Effect of refrigerated storage on lactic acid bacteria, and (a) *L. bulgaricus* count (b) *S. thermophilus* count of OFI-GYS and OFI-CYS

Conclusion: The present study demonstrated that incorporation of OFI fruit juice produced a functionally enriched goat milk yoghurt spread with satisfactory stability during refrigerated storage. The developed OFI-GYS maintained relatively stable physicochemical characteristics, including pH and total solids, while showing progressive improvement in water-holding capacity during storage. Although viscosity increased during refrigeration, the lower viscosity of OFI-GYS compared with the control was associated with better spreadability and a more desirable sensory texture.

The developed spread maintained viable populations of *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* above 10^6 CFU/g throughout 28 days of storage. The absence of yeasts, moulds, coliforms, *Escherichia coli* and coagulase-positive *Staphylococcus aureus* demonstrated satisfactory microbiological quality. The incorporation of OFI fruit juice also contributed to the antioxidant potential of the product, as reflected by its higher initial phenolic content and substantial radical-scavenging activity during storage.

Importantly, OFI-GYS exhibited superior retention of sensory quality compared with the control. At the end of 28 days, the developed product maintained acceptable flavour, colour and appearance, body and texture, spreadability and overall acceptability, with sensory scores remaining above the acceptable level. Based on the integrated physicochemical, microbiological and sensory results, a refrigerated shelf-life of 28 days at $4 \pm 1^\circ\text{C}$ was established for the developed product. Continued sensory acceptability up to 45 days, despite slight surface whey separation, indicates potential for further shelf-life extension following additional validation.

Overall, OFI fruit juice represents a promising functional ingredient for the development of a value-added goat milk yoghurt spread. The developed product combines the nutritional and functional attributes of goat milk and prickly pear fruit with satisfactory storage stability, thereby demonstrating potential for commercialization as an innovative functional fermented dairy product.

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